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DRAFT
TOTAL MAXIMUM DAILY LOAD (TMDL) FOR 65 ACID IMPAIRED NEW HAMPSHIRE PONDS

August 2004

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

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STATE OF NEW HAMPSHIRE

DRAFT TOTAL MAXIMUM DAILY LOAD (TMDL) FOR 65 ACID IMPAIRED NEW HAMPSHIRE PONDS

DEPARTMENT OF ENVIRONMENTAL SERVICES
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We also thank the U.S. Environmental Agency for providing the funding necessary to complete this project.

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

Section 303(d) of the Clean Water Act (CWA) and EPA's Water Quality Planning Regulations (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for water quality limited segments that are not meeting designated uses under technology-based controls for pollution. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollutant sources and lake water quality conditions, so that states can establish water quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources.

1.2 PURPOSE OF THIS STUDY

The purpose of this study is to develop a TMDL for 65 acid impaired New Hampshire lakes. A total of 76 lakes were listed on the State's 2004 303(d) list as a high priority because of pH values that exceed (are less than) the state's surface water quality criteria for the protection of aquatic life. To be listed as impaired for acidity, a lake needed a minimum of 10 samples in the last 10 year period and a minimum of 3 needed to be less than 6.5. Eleven impaired lakes were not included in this TMDL because of lack of data or borderline conditions (3 values were less than 6.5 but the average of the 10 values exceeded 6.5).

CHAPTER 2
PROBLEM STATEMENT

2.1 WATERBODY DESCRIPTION / FOCUS OF STUDY

Acid deposition (commonly called acid rain) occurs when emissions of sulfur dioxide (SO_2) or nitrogen oxides (NOx) react in the atmosphere with water, oxygen and oxidants to form acidic compounds. These compounds are carried varying distances from their source and are deposited as precipitation (rain, snow), as fog or as dry particles (dust). Acid deposition is a major environmental concern for a variety of reasons, including their toxic impact on the aquatic life of surface waters.

The New Hampshire Department of Environmental Services has been monitoring the impacts of acid rain in sensitive lakes since 1981 under the remote pond (30 lakes) and acid outlet (20 lakes) programs. In addition, lake pH is measured in the Volunteer Lake Assessment Program lakes (initiated in 1985 and now including 150 lakes) and in the Lake Trophic Survey program (initiated in 1975). The assessment of data from these various programs resulted in 76 lakes being listed as impaired for pH on the 2004 303(d) list. This Total Maximum Daily Load (TMDL) document determines the annual loading limits for 65 of the 76 impaired lakes. The lakes are listed and located in Figure 1 and the assessment unit IDs along with the lake name and town are provided in Table 1.

Because the source and type of the problematic loading was similar for all the lakes, a single analytical approach was used to determine each lake's acid loading capacity or critical load. This approach allowed the packaging of all the lake loading determinations into a single document.

This document provides the necessary information to satisfy requirements for TMDL development but not to explicitly give the derivation of the critical loading estimates for the 65 lakes. Attached to this document as Appendix A is a document entitled "*Calculating critical loads of acidity and exceedances for acid impaired lakes in New Hampshire using the steady state water chemistry (SSWC) model*". This document thoroughly examines the derivation of the critical loads for each lake.

The establishment of critical loads of acidity for these lakes provides an important component to fully document the acid depositional process. The critical loads establish the necessary levels of acidic deposition to each watershed to allow for the recovery of the lakes. However, additional information on distant sources and transport patterns are necessary to initiate proper controls. The critical load provides a framework from which to "backtrack" and trace the origin and magnitude of the acidity sources to the atmosphere and their transport to New Hampshire. Combined with atmospheric transport and deposition modeling, they will provide a basis for evaluating the environmental effectiveness of alternative national or regional emission control programs, or quantifying the adverse contributions from specific emission sources if effective national legislation is not forthcoming. They also provide a "benchmark" from which to quantitatively measure the effects of future changes in emissions and deposition. The critical loads established in this TMDL will facilitate a better understanding of the status and magnitude of acidic atmospheric deposition on New Hampshire lakes and ultimately lead to the control of significant acid sources.

Figure 1. Locational map of New Hampshire's acid impaired ponds

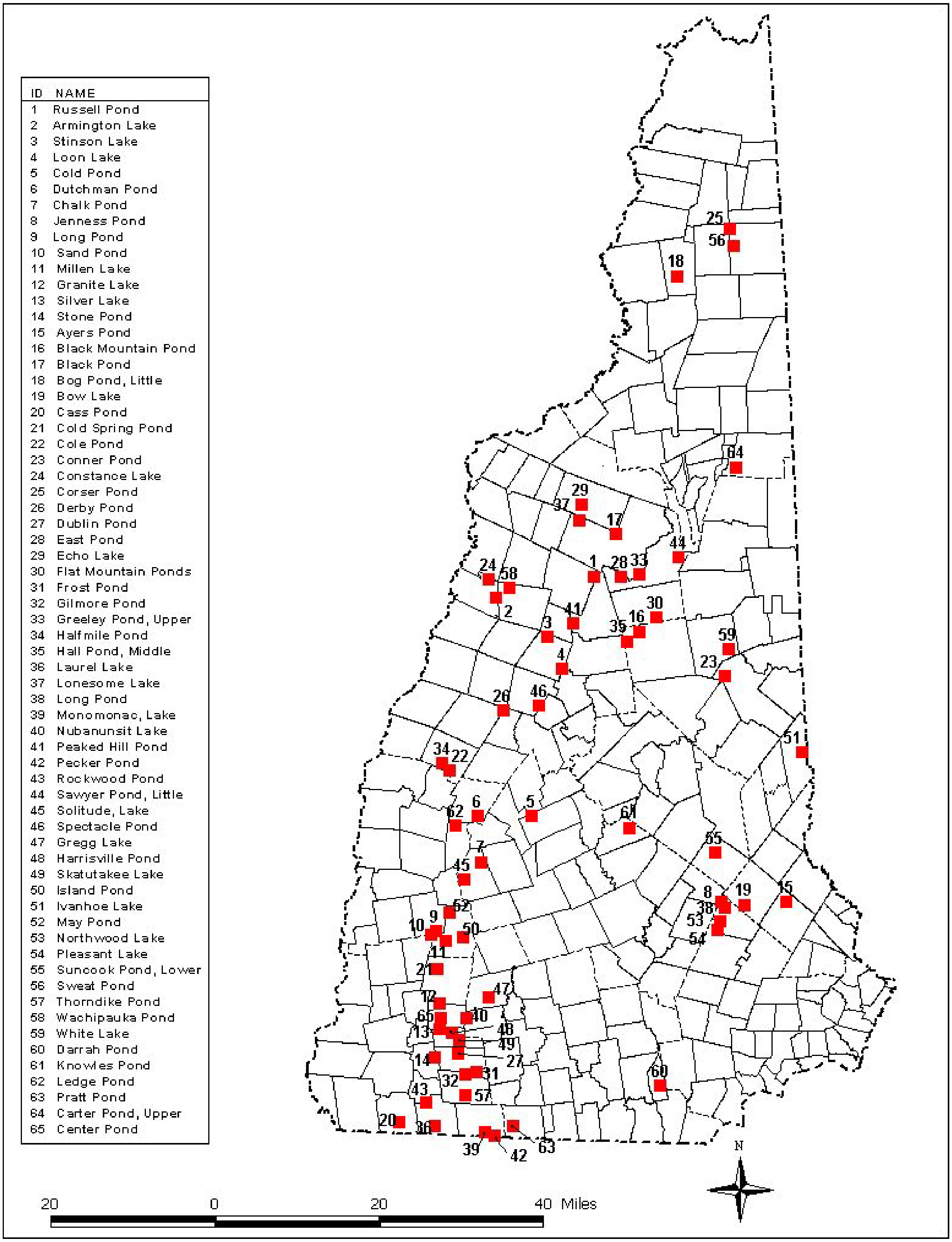

Table 1. Waterbody ID and lake name for acid impaired ponds

Waterbody ID	Lake	Town	Class
NHLAK801040201-01	ARMINGTON LAKE	PIERMONT	B
NHLAK600030607-01	AYERS POND	BARRINGTON	B
NHLAK700010402-01	BLACK MOUNTAIN POND	SANDWICH	B
NHLAK700010104-01	BLACK POND	LINCOLN	B
NHLAK801010706-01	BOG POND, LITTLE	ODELL	B
NHLAK600030604-01-01	BOW LAKE	STRAFFORD	B
NHLAK600020104-01	CARTER POND, UPPER	BEANS PURCHASE	B
NHLAK802020203-01	CASS POND	RICHMOND	B
NHLAK802010201-02	CENTER POND	NELSON	B
NHLAK801060402-03	CHALK POND	NEWBURY	B
NHLAK700030403-03	COLD POND	ANDOVER	B
NHLAK802010102-01	COLD SPRING POND	STODDARD	B
NHLAK801060105-01	COLE POND	ENFIELD	B
NHLAK600020802-02	CONNER POND	OSSIPEE	B
NHLAK801030701-01	CONSTANCE LAKE	PIERMONT	B
NHLAK400010502-02	CORSER POND	ERROL	B
NHLAK700061002-01-01	DARRAH POND	LITCHFIELD	B
NHLAK700010304-02	DERBY POND	CANAAN	B
NHLAK802010202-05	DUBLIN POND	DUBLIN	B
NHLAK801060402-06	DUTCHMAN POND	SPRINGFIELD	B
NHLAK700010204-01	EAST POND	LIVERMORE	B
NHLAK801030302-01-01	ECHO LAKE	FRANCONIA	B
NHLAK600020602-02	FLAT MOUNTAIN POND (1&2)	WATERVILLE	B
NHLAK700030102-02	FROST POND	JAFFREY	B
NHLAK700030101-05	GILMORE POND	JAFFREY	B
NHLAK802010201-05	GRANITE LAKE	STODDARD	B
NHLAK700010401-04	GREELEY POND (UPPER)	LIVERMORE	B
NHLAK700030108-02-01	GREGG LAKE	ANTRIM	B
NHLAK801060401-07	HALFMILE POND	ENFIELD	B
NHLAK700010402-04	HALL POND, MIDDLE	SANDWICH	B
NHLAK700030103-05-01	HARRISVILLE POND	HARRISVILLE	B
NHLAK700030204-03	ISLAND POND	WASHINGTON	B
NHLAK600030403-03	IVANHOE, LAKE	WAKEFIELD	B
NHLAK700060502-06	JENNESS POND	NORTHWOOD	B
NHIMP700020203-01	KNOWLES POND	NORTHFIELD	A
NHLAK802020202-02-01	LAUREL LAKE	FITZWILLIAM	B
NHLAK801060402-08	LEDGE POND	SUNAPEE	A
NHLAK700010201-03	LONESOME LAKE	LINCOLN	B
NHLAK802010101-04	LONG POND	LEMPSTER	B
NHLAK700060502-07	LONG POND	NORTHWOOD	B
NHLAK700010307-01	LOON LAKE	PLYMOUTH	B
NHLAK802010101-05	MAY POND	WASHINGTON	B
NHLAK802010101-06-01	MILLEN POND	WASHINGTON	B
NHLAK802020103-06	MONOMONAC, LAKE	RINDGE	B
NHLAK700060502-08-01	NORTHWOOD LAKE	NORTHWOOD	B
NHLAK700030103-07	NUBANUSIT LAKE	NELSON	B
NHLAK700010205-02	PEAKED HILL POND	THORNTON	B
NHLAK802020101-01	PECKER POND	RINDGE	B
NHLAK700060502-09-01	PLEASANT LAKE	DEERFIELD	B
NHLAK700060901-03	PRATT POND	NEW IPSWICH	B

Waterbody ID	Lake	Town	Class
NHLAK802010303-04	ROCKWOOD POND	FITZWILLIAM	B
NHLAK700010203-02	RUSSELL POND	WOODSTOCK	B
NHLAK802010101-08	SAND POND	MARLOW	B
NHLAK600020102-02	SAWYER POND, LITTLE	LIVERMORE	B
NHLAK802010202-09	SILVER LAKE	HARRISVILLE	B
NHLAK700030103-08	SKATUTAKEE, LAKE	HARRISVILLE	B
NHLAK700030301-01	SOLITUDE, LAKE	NEWBURY	B
NHLAK700010601-01	SPECTACLE POND	GROTON	B
NHLAK700010306-01	STINSON LAKE	RUMNEY	B
NHLAK802010303-05-01	STONE POND	MARLBOROUGH	B
NHLAK700060402-10-01	SUNCOOK POND, LOWER	BARNSTEAD	B
NHLAK400010502-05	SWEAT POND	ERROL	B
NHLAK700030102-01-01	THORNDIKE POND	JAFFREY	B
NHLAK700010302-02	WACHIPAUKA POND	WARREN	B
NHLAK600020605-02-01	WHITE LAKE	TAMWORTH	A

2.2 APPLICABLE WATER QUALITY STANDARDS

2.2.1 Overview

Water Quality Standards determine the baseline water quality that all surface waters of the State must meet in order to protect their intended uses. They are the "yardstick" for identifying where water quality violations exist and for determining the effectiveness of regulatory pollution control and prevention programs. The standards are composed of three parts: classification, criteria, and antidegradation regulations.

Classification of surface waters is accomplished by state legislation under the authority of RSA 485-A:9 and RSA 485-A:10. By definition, (RSA 485-A:2, XIV), "surface waters of the state means streams, lakes, ponds, and tidal waters within the jurisdiction of the state, including all streams, lakes, or ponds, bordering on the state, marshes, water courses and other bodies of water, natural or artificial".

All State surface waters are either classified as Class A or Class B, with the majority of waters being Class B. DES maintains a list which includes a narrative description of all the legislative classified waters. Designated uses for each classification may be found in State statute RSA 485-A:8 and are summarized below.

Classification	Designated Uses
Class A -	These are generally of the highest quality and are considered potentially usable for water supply after adequate treatment. Discharge of sewage or wastes is prohibited to waters of this classification.
Class B -	Of the second highest quality, these waters are considered acceptable for fishing, swimming and other recreational purposes, and, after adequate treatment, for use as water supplies.

The second major component of the water quality standards is the "criteria". These are numerical or narrative criteria which define the water quality requirements for Class A or Class B waters. Criteria assigned to each classification are designed to protect the legislative designated uses for each classification. A waterbody that meets the criteria for its assigned classification is considered to meet its intended use. Water quality criteria for each classification may be found in RSA 485-A:8, I-V and in the State of New Hampshire Surface Water Quality Regulations (Env-Ws 1700)

The third component of water quality standards are antidegradation provisions which are designed to preserve and protect the existing beneficial uses of the State's surface waters and to limit the degradation allowed in receiving waters. Antidegradation regulations are included in Part Env-Ws 1708 of the New Hampshire Surface Water Quality Regulations. According to Env-Ws 430.31, antidegradation applies to the following:

* all new or increased activity, including point and nonpoint source discharges of pollutants that would lower water quality or affect the existing or designated uses;
* a proposed increase in loadings to a waterbody when the proposal is associated with existing activities;
* an increase in flow alteration over an existing alteration; and
* all hydrologic modifications, such as dam construction and water withdrawals.

2.2.2 Water Quality Standards Most Applicable to the Pollutant of Concern

This TMDL report is for ponds impaired because of excess acidity. The water quality criteria that applies to acidity is pH. Under RSA 485-A:8 and Env-Ws 1703.18, the pH criteria is:

The pH of Class A waters shall be as naturally occurs.

The pH of Class B waters shall be 6.5 to 8.0, unless due to natural causes.

Based on New Hampshire's Consolidated Assessment and Listing Methodology or CALM (NHDES, 2004) for listing impaired waters, low pH exceedances in waters where the apparent color was greater than 30 color units (based on visual comparisons to potassium chloroplatinate standards) were considered to be due to natural causes (i.e., natural tannic and humic acids in the water). The criterion for Class A waters is interpreted as the same as for Class B: the pH is considered natural unless the pH is less than 6.5 and the color is 30 or less. To list a lake as impaired due to pH, at least 10 data points are required, at least three out of the 10 are less than 6.5, and the color is 30 or less. Waters on the impaired list due to pH exceedances are listed as impaired for the aquatic life use.

2.3 TARGETED WATER QUALITY GOALS

Acid neutralizing capacity (ANC) of water is the endpoint of the SSWC model used to calculate critical loads of acidity. While pH is a measure of the acidity (and violations of the pH criterion is the reason for the impaired listing), ANC is used as the endpoint of the model because ANC is the best criterion for the protection of aquatic life. An ANC of 2.5 mg/L is generally considered to provide adequate buffering to acid inputs to protect aquatic life. However, the goal of this TMDL is to reduce the amount of acid deposition to the lakes not only to protect aquatic life but to allow the pH values to return to the water quality criterion level of 6.5. To use the model, a target ANC needs to be selected. A regression of pH and ANC for the lakes in question determined that an ANC of 3 mg/L (60 ueq/L) was approximately equivalent to a pH of 6.5 and was selected as the target goal (see Figure 1 in Appendix A).

The purpose of the TMDL is to link acidic loading to a lake's ANC and to quantify the maximum amount of acidity a watershed can receive and maintain the target ANC to protect aquatic life.

2.4 EVIDENCE OF WATER QUALITY IMPAIRMENT

Appendix A describes the monitoring programs providing data used to assess lakes for impairment and Table 1 in Appendix I of Appendix A lists the average pH and ANC (alkalinity) values used in the model. All 65 lakes were listed on the 2004 303(d) list because at least three pH values out of 10 were below 6.5. For a few lakes, the average pH value used in the model was 6.5 or higher. Impairments under New Hampshire's Consolidated Assessment Listing Methodology are based on number of exceedances of a criterion and not on an average value. Thus an average value can meet a criterion despite sufficient exceedances of the criterion to cause an impairment listing.

CHAPTER 3
EXISTING POINT AND
NONPOINT SOURCE LOADS

3.1 EXISTING POINT SOURCE LOADS

No known point sources of low pH discharges occur to the lakes nor are present in the watersheds of the lakes evaluated in this TMDL.

3.2 EXISTING NONPOINT SOURCE LOADS

It has long been understood that the deposition of strong mineral acids and acid forming compounds from the atmosphere have been the primary source of the acidification of hundreds of lakes throughout northeast North America as well as in other regions of the country and the world. The overwhelming source of acidity to these lake watersheds is from atmospheric deposition through rain, snow, fog and dust, and the source of the acids in the atmosphere is the emission of sulfur dioxides (SO_2) and nitrogen oxides (NO_x) from a variety of sources. While the specific sources of these acidifying pollutants are not identified here, national atmospheric emission inventories and decades of atmospheric modeling results clearly implicate “Midwestern” coal-fired electric utilities as a predominant historical and continuing source of wet and dry sulfate depositions in New England (and eastern Canada). Nitric acid deposition is also heavily contributed to by coal-fired utilities but also results from a broader range of emission source types including motor vehicles and industrial sources. From a water quality perspective, it is not the atmospheric concentrations but rather the atmospheric cleansing or deposition of these pollutants that matters.

CHAPTER 4
TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS

4.1 DEFINITION OF A TMDL

According to the 40 CFR Part 130.2, the total maximum daily load (TMDL) for a waterbody is equal to the sum of the individual loads from point sources (i.e., wasteload allocations or WLAs), and load allocations (LAs) from nonpoint sources (including natural background conditions). Section 303(d) of the CWA also states that the TMDL must be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety (MOS) which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.

In equation form, a TMDL may be expressed as follows:

TMDL = WLA + LA + MOS

where:

WLA	=	Waste Load Allocation (i.e. loadings from point sources)
LA	=	Load Allocation (i.e., loadings from nonpoint sources including natural background)
MOS	=	Margin of Safety

TMDLs can be expressed in terms of either mass per time, toxicity or other appropriate measure [40 CFR, Part 130.2 (i)]. The MOS can be either explicit or implicit. If an explicit MOS is used, a portion of the total allowable loading is actually allocated to the MOS. If the MOS is implicit, a specific value is not assigned to the MOS. Use of an implicit MOS is appropriate when assumptions used to develop the TMDL are believed to be so conservative that they are sufficient to account for the MOS.

4.2 DETERMINATION OF TOTAL MAXIMUM DAILY LOAD (LOADING CAPACITY)

4.2.1 Seasonal Considerations/Critical Conditions

Due to the long-term nature and variability of acidic deposition, both wet and dry, and the watershed and internal lake processes that occur over long periods of time, it is more appropriate to express the load as an annual load rather than a daily load. A daily loading limit would be difficult to determine and of little use. It is the overall annual acid loading that affects the lake pH and ANC, and ultimately the biological communities.

Critical loads should be calculated using yearly average values of lake conditions but, to be more protective, are sometimes calculated using minimum values or spring time values. It is during the spring snowmelt runoff events, often associated with rain events that the annual acidity load peaks. As discussed in Section 2.1 above and in Appendix A, data for this analysis comes from a variety of monitoring programs and represent average values. Spring overturn, fall overturn and summer values were all used. Critical loads calculated using average annual data may not be fully protective for the worst case conditions of the spring.

4.2.2 Margin of Safety

The TMDL regulations require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between loading and attainment of water quality standards. In 2003, Vermont conducted a similar TMDL for its acid ponds and used a 5% margin of safety based on the fact that most of the data was current (5 years or less old) and site specific. This TMDL also used site specific data but some of the data was greater than 5 years old and some summer data was used, which may be less protective than spring time data. For these reasons, a slightly higher margin of safety (7.5 %) was used for this TMDL.

4.2.3 TMDL Calculation and Load Allocation

The purpose of the TMDL is to provide the link between acidic loadings and a lake's ANC by quantifying the maximum amount of acidity the watershed can receive to maintain the selected ANC. For this TMDL the Steady State Water Chemistry (SSWC) model was used to make this connection. Since the source of all the acidity is considered to be non-point, the waste load allocation is equal to zero and the TMDL or critical load is:

TMDL = load allocation + margin of safety

A brief description of the SSWC model is provided here; for a more detailed description, refer to Appendix A.

The SSWC model estimates the critical load of acidity to a watershed where the critical load is defined as the level below which significant harmful effects to specified elements of the environment do not occur. The underlying concept of the model is that excess base cations in a catchment should be equal to or greater than the acid anion inputs. This balance maintains the lake's ANC to support aquatic communities. The SSWC model has been used for critical load determinations in areas where acid deposition is a problem, namely northern Europe and Canada, and was used by the State of Vermont for an acid pond TMDL.

The SSWC model calculates critical loads based on in-lake water chemistry and accounts for annual surface runoff amounts and a user specified ANC limit. The ability to set a predefined ANC limit forces the model to output a critical load based directly on New Hampshire's water quality target of 3 mg/L of ANC. The critical load for each of the 65 lakes is given in Table 2 below.

Table 2. Critical load of acidity for acid impaired ponds

Waterbody Name	Critical Load meq/m²/yr	Waterbody Name	Critical Load meq/m²/yr	Waterbody Name	Critical Load meq/m²/yr
Armington Lake	67.63	Flat Mountain Ponds	22.83	Northwood Lake	60.94
Ayers Pond	32.22	Frost Pond	40.80	Nubanusit Lake	52.81
Black Mountain Pond	41.38	Gilmore Pond	-18.01	Peaked Hill Pond	47.54
Black Pond	105.58	Granite Lake	70.92	Pecker Pond	32.34
Bog Pond, little	99.37	Greeley Pond (Upper)	149.24	Pleasant Lake	45.26
Bow Lake	73.53	Gregg Lake	40.66	Pratt Pond	40.83
Carter Pond, upper	39.74	Halfmile Pond	21.06	Rockwood Pond	38.62
Cass Pond	63.88	Hall Pond, Middle	56.43	Russell Pond	88.70
Center Pond	61.08	Harrisville Pond	57.50	Sand Pond	-45.11
Chalk Pond	31.43	Island Pond	-146.53	Sawyer Pond, Little	91.44
Cold Pond	27.56	Ivanhoe, Lake	17.85	Silver Lake	54.81
Cold Spring Pond	45.48	Jenness Pond	42.61	Skatutakee, Lake	32.40
Cole Pond	58.06	Knowles Pond	24.89	Solitude, Lake	30.84
Conner Pond	59.58	Laurel Lake	32.71	Spectacle Pond	59.75
Constance Lake	-10.39	Ledge Pond	38.42	Stinson Lake	86.21
Corser Pond	21.61	Lonesome Lake	56.75	Stone Pond	61.99
Darrah Pond	-8.14	Long Pond	50.63	Suncook Pond, Lower	57.67
Derby Pond	44.36	Long Pond	53.43	Sweat Pond	53.81
Dublin Pond	53.28	Loon Lake	92.28	Thorndike Pond	42.66
Dutchman Pond	46.44	May Pond	41.33	Wachipauka Pond	71.67
East Pond	36.18	Millen Pond	38.26	White Lake	42.35
Echo Lake	17.94	Monomonac, Lake	14.47		

Positive critical load values indicate that the waterbody has some tolerance for acidic inputs and still be able to maintain the target ANC of 3.0 mg/L. The greater the critical load, the greater the tolerance of the waterbody to acid inputs. On the other hand, negative critical loads represent situations where the selected ANC target of 3.0 mg/L is higher than the original, pre-acidification, base cation concentrations would naturally allow. For these lakes the critical load is zero. In other words, these lakes can accept no acid loadings and, in fact, if loadings were reduced to zero, acidic conditions would continue.

The use of the SSWC model for critical load determination has many benefits. First, the model has a successful track record in northern Europe and Canada supporting establishment of source reduction targets. Second, the inputs for the model were generally available so that only limited additional data collection was required. Third, the model has the flexibility to adapt to the user-specific ANC target. This flexibility allows the direct output of the necessary critical loads without additional extrapolation.

The primary weakness of the model is not in its ability to calculate critical loads, but rather in its inability to predict responses to reduced deposition. For example, a reduction in acid loading may alter current weathering rates, soil base cation depletion or mineralization rates. Any of these changes may affect the future critical load. However, under the steady state conditions required by the model, the critical loading limits in this TMDL are the best estimates available with current data.

4.3 LOAD REDUCTIONS NEEDED TO ACHIEVE THE TMDL

In addition to the critical loads, exceedances of the critical load can be determined by comparing the critical load to recent loading estimates of acidic nitrogen and sulfur compounds. While the calculation of exceedances (see Table 3 below) is not critical for the TMDL, it does provide a means to gauge the extent of the impairment and the level of reductions needed. Exceedances also demonstrate the range of sensitivity of New Hampshire's acid impaired lakes. While some lakes may improve with modest reductions in acid inputs, others require far greater reductions to achieve recovery. Positive excess load values indicate that a lake's critical load has been exceeded based on the SSWC model output compared to depositional data. A negative value indicates that the critical load was not exceeded.

Table 3. Calculated critical load exceedances for acid impaired ponds

Waterbody Name	Critical Load Exceedances meq/m^2/yr	Waterbody Name	Critical Load Exceedances meq/m^2/yr	Waterbody Name	Critical Load Exceedances meq/m^2/yr
Armington Lake	-38.26	Flat Mountain Ponds	18.94	Northwood Lake	-35.23
Ayers Pond	-9.59	Frost Pond	-8.56	Nubanusit Lake	-18.96
Black Mountain Pond	-1.93	Gilmore Pond	32.20	Peaked Hill Pond	-18.86
Black Pond	-75.51	Granite Lake	-36.59	Pecker Pond	1.74
Bog Pond, Little	-62.09	Greeley Pond (Upper)	-79.15	Pleasant Lake	-19.59
Bow Lake	-47.92	Gregg Lake	-9.04	Pratt Pond	-7.09
Carter Pond, Upper	12.09	Halfmile Pond	11.37	Rockwood Pond	-4.96
Cass Pond	-31.18	Hall Pond, Middle	-23.95	Russell Pond	-57.01
Center Pond	-26.84	Harrisville Pond	-23.74	Sand Pond	34.39
Chalk Pond	-0.49	Island Pond	34.68	Sawyer Pond, Little	-45.72
Cold Pond	3.00	Ivanhoe, Lake	6.81	Silver Lake	-21.21
Cold Spring Pond	-9.87	Jenness Pond	-16.49	Skatutakee, Lake	1.43
Cole Pond	-26.69	Knowles Pond	1.20	Solitude, Lake	9.36
Conner Pond	-32.32	Laurel Lake	-0.07	Spectacle Pond	-33.16
Constance Lake	30.48	Ledge Pond	-7.01	Stinson Lake	-52.76
Corser Pond	6.49	Lonesome Lake	-7.85	Stone Pond	-28.58
Darrah Pond	25.94	Long Pond	-16.20	Suncook Pond, Lower	-31.79
Derby Pond	-10.03	Long Pond	-27.86	Sweat Pond	-25.43
Dublin Pond	-19.26	Loon Lake	-66.28	Thorndike Pond	-8.49
Dutchman Pond	-14.40	May Pond	-6.75	Wachipauka Pond	-42.65
East Pond	16.00	Millen Pond	-3.08	White Lake	-18.48
Echo Lake	32.88	Monomonac, Lake	18.96		

The primary source of acidity to these lakes is from wet and dry atmospheric deposition. As previously noted, the ultimate source of this atmospheric acidity is air emissions, primarily from fossil fuel burning power plants and motor vehicles. While these emissions can originate both within New Hampshire and outside the state and region, the mid-western region (the seven states of the Ohio River Valley) of the United States emits the greatest amount of sulfur and nitrogen oxides of any region in the nation (Driscoll, et al., 2001a).

Smokestacks and tailpipes and the atmospheric acid they emit appear to meet the definition of point source and pollutant. However, smokestack and tailpipe-related emissions have not been traditionally regulated under the Clean Water Act. Therefore, for the purposes of this TMDL, the total pollutant load, minus the explicit margin of safety, is allocated to nonpoint sources. Because of the difficulty of determining the specific air contaminant sources polluting New Hampshire's waters, no attempt has been made to sub-allocate the load allocation among either different geographic regions or types of sources of atmospheric acid.

Table 4 below summarizes the acid allocations for all 65 of the acid impaired waters covered under this TMDL.

Table 4. TMDLs and Allocations for NH Acid Ponds

Waterbody Name	Waste Load Allocation (meq/m^2/yr)	Load Allocation (meq/m^2/yr)	Margin of Safety (meq/m^2/yr)	TDML (Critical Load) (meq/m^2/yr)
Armington Lake	0	62.55	5.07	67.63
Ayers Pond	0	29.80	2.42	32.22
Black Mountain Pond	0	38.28	3.10	41.38
Black Pond	0	97.66	7.92	105.58
Bog Pond, Little	0	91.91	7.45	99.37
Bow Lake	0	68.02	5.51	73.53
Carter Pond, Upper	0	36.76	2.98	39.74
Cass Pond	0	59.09	4.79	63.88
Center Pond	0	56.50	4.58	61.08
Chalk Pond	0	29.08	2.36	31.43
Cold Pond	0	25.49	2.07	27.56
Cold Spring Pond	0	42.07	3.41	45.48
Cole Pond	0	53.71	4.35	58.06
Conner Pond	0	55.11	4.47	59.58
Constance Lake	0	-11.17	0.78	-10.39
Corser Pond	0	19.99	1.62	21.61
Darrah Pond	0	-8.75	0.61	-8.14
Derby Pond	0	41.04	3.33	44.36
Dublin Pond	0	49.28	4.00	53.28
Dutchman Pond	0	42.95	3.48	46.44
East Pond	0	33.47	2.71	36.18
Echo Lake	0	16.59	1.35	17.94
Flat Mountain Pond (1&2)	0	21.12	1.71	22.83
Frost Pond	0	37.74	3.06	40.80
Gilmore Pond	0	-19.37	1.35	-18.01
Granite Lake	0	65.60	5.32	70.92
Greeley Pond (Upper)	0	138.05	11.19	149.24
Gregg Lake	0	37.61	3.05	40.66
Halfmile Pond	0	19.48	1.58	21.06
Hall Pond, Middle	0	52.20	4.23	56.43
Harrisville Pond	0	53.19	4.31	57.50
Island Pond	0	-157.52	10.99	-146.53
Ivanhoe, Lake	0	16.51	1.34	17.85
Jenness Pond	0	39.41	3.20	42.61
Knowles Pond	0	23.02	1.87	24.89
Laurel Lake	0	30.26	2.45	32.71
Ledge Pond	0	35.53	2.88	38.42
Lonesome Lake	0	52.49	4.26	56.75
Long Pond	0	46.83	3.80	50.63
Long Pond	0	49.43	4.01	53.43
Loon Lake	0	85.36	6.92	92.28
May Pond	0	38.23	3.10	41.33
Millen Pond	0	35.39	2.87	38.26
Monomonac, Lake	0	13.39	1.09	14.47
Northwood Lake	0	56.37	4.57	60.94
Nubanusit Lake	0	48.85	3.96	52.81
Peaked Hill Pond	0	43.98	3.57	47.54
Pecker Pond	0	29.91	2.43	32.34
Pleasant Lake	0	41.87	3.39	45.26
Pratt Pond	0	37.77	3.06	40.83
Rockwood Pond	0	35.72	2.90	38.62
Russell Pond	0	82.05	6.65	88.70
Sand Pond	0	-48.50	3.38	-45.11
Sawyer Pond, Little	0	84.58	6.86	91.44
Silver Lake	0	50.70	4.11	54.81
Skatutakee, Lake	0	29.97	2.43	32.40

Waterbody Name	Waste Load Allocation (meq/m^2/yr)	Load Allocation (meq/m^2/yr)	Margin of Safety (meq/m^2/yr)	TDML (Critical Load) (meq/m^2/yr)
Solitude, Lake	0	28.53	2.31	30.84
Spectacle Pond	0	55.27	4.48	59.75
Stinson Lake	0	79.74	6.47	86.21
Stone Pond	0	57.34	4.65	61.99
Suncook Pond, Lower	0	53.35	4.33	57.67
Sweat Pond	0	49.77	4.04	53.81
Thorndike Pond	0	39.46	3.20	42.66
Wachipauka Pond	0	66.30	5.38	71.67
White Lake	0	39.17	3.18	42.35

CHAPTER 5
IMPLEMENTATION / REASONABLE ASSURANCE

5.1 STATUTORY/REGULATORY REQUIREMENTS

Section 303(d)(1)(C) of the CWA provides that TMDLs must be established at a level necessary to implement the applicable water quality standard. The following is a description of activities that have been implemented or proposed to restore acid impaired ponds in New Hampshire.

5.2 DESCRIPTION OF ACTIVTIES TO ACHIEVE TMDL

5.2.1 Implementation Plan

The New Hampshire Department of Environmental Services, Air Resources Division, maintains a *New Hampshire Clean Air Strategy* (NHDES, 1994) that contains an acid deposition component and is updated periodically. Sulfur emissions in NH are regulated by the department under both the federal Clean Air Act amendments and the state New Hampshire Acid Deposition Control Program (RSA 125-D and Env-A 400). DES launched a *Clean Power Strategy* in early 2001 to reduce emissions of four harmful air pollutants (SO_2, NO_x, mercury and CO_2) beyond reductions already required by existing state and federal programs, at three fossil fuel-burning power plants in New Hampshire.

NHDES is an active participant in the New England Governors and Eastern Canadian Premiers (NEG/ECP) Acid Rain Action Plan and has supported the adoption of the plan and goals to further reduce sulfur and nitrogen oxide emissions. The Action Plan calls for U.S. and Canadian reductions of sulfur dioxide emissions by an amount 50% greater than the current commitments by 2010, and reductions of nitrogen oxide emissions by an amount 20-30% greater than current commitments by 2007.

New Hampshire will continue to work with the state legislature and participate in the NEG/ECP conference to pursue all appropriate available avenues and adopt new and innovative strategies to reduce sulfur and nitrogen oxide emissions within the state. However, as discussed earlier, the bulk of the acidifying pollutants contributing to the acid impairments identified in this TMDL are from sources well beyond New Hampshire's borders. Because of sensitive ecosystems and high deposition rates, aquatic resources in New Hampshire, as well as all of northeast North America, continue to suffer more damage from acidic deposition than other regions of the country. Aside from participating in litigation to uphold federal requirements, New Hampshire has little direct control over these sources and is forced to rely on national enforcement efforts spearheaded by the USEPA. It is expected that reductions in upwind emissions of acidifying pollutants are needed to reduce the critical load exceedances in New Hampshire's acid impaired ponds

In short, implementation of this TMDL is primarily the responsibility of EPA. EPA began to address acid rain and other water quality impairing air contaminants under Title IV and section 112m of the Clean Air Act. However, 14 years after the Clean Air Act amendments of 1990 the problem of acid impaired waters remains. The USGAO (2000), USEPA (2003) and others (e.g., Driscoll, et al, 2001b; Jeffries, et al, 2003) have all concluded that, despite reductions in sulfur emissions and deposition, reduction targets in existing legislation are not sufficient for recovery in sensitive ecosystems and additional reductions are required. The solution is for EPA to work with the up-wind mid-western states to achieve significant reductions in sulfur and nitrogen oxide emissions from stationary and mobile sources.

5.2.2 Monitoring

DES plans to continue to monitor acid rain related parameters in the lakes and ponds of the state. As national efforts to control acid deposition to the northeast progresses, DES anticipates the ability to identify resultant changes to the waterbodies. DES will also continue to provide acid pond data for a selected 20 ponds to the NEG/ECP WARNING (Water Acidity Regional Network to Inform Northeast Governments) Network. The network collects acid rain data from the states and provinces of the region and periodically evaluates trends.

As described in more detail in Appendix A, DES has four lake monitoring programs that provided data for this 65-pond acid pond TMDL. Thirty-seven of the ponds were sampled annually as part of the remote pond (19 ponds) or semi-annually as part of the acid outlet (18 ponds) programs designed specifically to monitor trends in acid rain related parameters. Data for the remaining 28 lakes were from lake trophic surveys conducted once every 15 to 25 years or from volunteer lake monitoring (VLAP) sampling conducted three times per year each year during the summer. Twenty-four of these 28 lakes were in the VLAP program. Clearly the trophic surveys are not conducted at a frequency that lends itself for trend analyses. VLAP provides trend data for pH and ANC but cations and anions are not analyzed.

CHAPTER 6
PUBLIC PARTICIPATION

6.1 DESCRIPTION OF PUBLIC PARTICIPATION PROCESS

EPA regulations [40 CFR 130.7 (c) (ii)] require that calculations to establish TMDLs be subject to public review.

(This section will be filled in after the public participation process is completed.)

6.2 PUBLIC COMMENT AND DES RESPONSE

(This section will be filled in after the public participation process is completed.)

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Appendix A

SSWC Model Application:

Calculating critical loads of acidity for acid-impaired New Hampshire lakes using the Steady State Water Chemistry (SSWC) model

ACKNOWLEDGEMENTS:

We give special thanks to Heather Pembrook of Vermont DEC who wrote the Vermont acid ponds TMDL, and to Tim Clear, TMDL coordinator for VTDEC who provided the critical loads spreadsheet and many of the bibliographic reprints. This TMDL is modeled on the Vermont acid pond TMDL, which we unabashedly plagiarized.

Calculating critical loads of acidity for acid-impaired New Hampshire lakes using the Steady State Water Chemistry (SSWC) model

Abstract

A critical load model was applied to 65 of New Hampshire's acid impaired ponds. Critical loads were calculated using the Steady State Water Chemistry (SSWC) model of Henriksen and Posch (2001).

Background

New Hampshire listed 76 ponds on the 2004 303(d) list as being impaired for the aquatic life use because of low pH. To list as impaired, a pond must have at least 10 data points within the past 10 years and at least 3 of the 10 data points must exceed the standard. For pH, at least three of the 10 pH values needed to be less than 6.5 to be listed as impaired. Data used to assess ponds for impairment came from several monitoring programs. The monitoring programs are described below.

> **Remote ponds**: These are mostly high elevation, remote ponds. They are sampled, mid-pond at 0.5 meter depth in the spring by helicopter. Analysis of the complete suite of cations and anions began in 2000. An average of fours years (2000-2003) of data was used for ponds sampled under this program.
>
> **Outlet ponds**: For these ponds the outlets are sampled during spring and fall overturn when outlet water represents average in-lake values. The complete suite of anions and cations were analyzed beginning in the fall of 1999. For these lakes, an average of nine data sets was used (fall, 1999 through fall, 2003).
>
> **Trophic survey lakes**: Most New Hampshire lakes have been sampled at one time or another under this program. The complete suite of ions is sampled during the summer at the deep spot in the mid-epilimnion or upper one-third of depth for unstratified lakes. However, sampling occurs only once every 10 to 20 years in this program so much of the data is dated. If data was available from one of the above programs, survey data was used only if it occurred during the same time period as the above data. If data was not available from the above two programs, survey data was used, regardless of age (up to 20 years old).
>
> **Volunteer Lake Assessment Program:** Lakes are sampled every year, usually three times per year during the summer period, in this program. Samples are collected during the summer at the deep spot in the mid-epilimnion or upper one-third of depth for unstratified lakes. The pH data from this program was used for use impairment assessments, but the program does not collect the anion and cation data needed for the critical loads model. Recent (last three years) pH and ANC (acid neutralizing capacity) data was used from this program for determining average lake values, but the ion data was from the other programs.

Data required for calculating critical loads of acidity are:

> Base cations: Ca, Mg, Na, K
> Anions: SO_4, NO_3, Cl
> Runoff

Some of the available cation and anion data was below the detectable limit and expressed as a "less than" value. The table below depicts how these "less than' values were used.

parameter	"less than" value (mg/L)	value used (mg/L)
Ca	1	0.5
K	0.4	0.2
Na	1	0.5
NO_3-N	0.02	0.01
	0.05	0.025
Cl	2 or 3	*1 or 0.5

* if all chloride values for a particular pond were below detectable (usually the case for the remote ponds), a value of 0.5 mg/L (14 ueq/L) was used (this is based on literature data of chloride values in the northeast remote from road salts); if one or more chloride value was at or above the detectable limit, then a < 2 or < 3 value was listed a 1 mg/L.

Critical loads should be calculated with a yearly average value but are often calculated from a single sample collected in the fall that represents a yearly average (Henriksen and Posch, 2001). Others (Wilander, 2001) have suggested that a minimum value is better than a median value to better protect a lake. In their TMDL submittal, Vermont used spring time values (typically minimum values) for approximately one-half of the lakes and data often collected outside the spring period for the remaining lakes (VTDEC, 2003). For this exercise, average values were used, which, as discussed above, may be spring samples, spring and fall samples, summer samples or a combination of all three seasons.

Introduction

The critical loads concept is widely accepted and used in Europe (Henriksen and Posch, 2001) and Canada (Dupont, et al., 2002; Henriksen et al., 2002; Hindar and Henriksen, 1998), but has been criticized by the USEPA (Thornton, 1991) because of its assumptions and lack of predictive capability. However, the dynamic models favored by EPA require much more data and are more complicated and expensive to run. NHDES selected the SSWC model for calculating TMDLs on acid impaired lakes because of its use on similar lakes in eastern Canada, because it is particularly applicable to dilute waters located in granitic bedrock with a thin overburden such as are found in NH and because the State of Vermont used it in 2003 to submit TMDLs for acid impaired Vermont lakes that were approved by USEPA.

The Steady State Water Chemistry model calculates critical loads of acidity based on in-lake water chemistry. A critical load is defined as "a quantitative estimate of the loading of one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not likely to occur according to present knowledge" (Nilsson and Grennfelt as quoted in Curtis, et al., 2001). Sulfate and nitrate are the major contributors to lake acidification in the northeast and are the pollutants of concern for this TMDL. The model also calculates exceedances of the critical load based on sulfate and nitrate contributions. Exceedances of the critical load are defined as the amount of excess acid above the critical load.

In order to determine a critical load, a critical chemical value for a biological indicator needs to be set. While pH is the measure of acidity (and the reason for impairment listing in New Hampshire), ANC is generally thought to be the better chemical criterion for biological response (Wilander, 2001) and is the endpoint used in the SSWC model. In using the model to calculate TMDLs for ponds violating New Hampshire's pH criterion, the model is used not to necessarily protect biota but to meet a chemical criterion (biological impairment generally doesn't occur until a pH of 6 or less is reached whereas NH's pH criterion is 6.5). The key for using the model is to select an ANC limit that is approximately equivalent to a pH of 6.5. Dupont, et al., (2002) discussed relationships between pH and ANC and quoted Sutton and Small as determining that an ANC of 2 mg/L (40 ueq/L) corresponds to a pH of 6 for Quebec lakes. Vermont used an ANC of 2.5 mg/L (50 ueq/L) as the endpoint for their TMDL calculations .

For this TMDL, an ANC of 3 mg/L (60 ueq/L) was selected as the end point for calculating critical loads for attaining NH's pH criterion of 6.5 (see Figure 1 of this appendix).

Study area

See Figure 1 on page 3 in the TMDL report for a map showing the location of the 65 acid impaired ponds. Table 1 below lists the ponds along with basic physical characteristics.

Table 1. Physical characteristics of NH's acid impaired ponds

Lake	Town	Class	Surface area (ha)	Maximum depth (m)	Drainage area (ha)	Elevation (m)
ARMINGTON LAKE	PIERMONT	B	57.55	9.7	676.5	407
AYERS POND	BARRINGTON	B	92.11	9.1	601	71
BLACK MOUNTAIN POND	SANDWICH	B	2.43	9.8	78.4	690
BLACK POND	LINCOLN	B	2.43	13.5	33.9	503
BOG POND, LITTLE	ODELL	B	14.97	3	1238.1	622
BOW LAKE	STRAFFORD	B	469.72	21	3692.7	157
CARTER POND, UPPER	BEANS PURCHASE	B	0.44	4.6	7.7	1003
CASS POND	RICHMOND	B	19.59	7.9	82.8	321
CENTER POND	NELSON	B	14.57	10.9	193.8	430
CHALK POND	NEWBURY	B	8.5	3.6	114.1	382
COLD POND	ANDOVER	A	5.99	5.5	271.1	329
COLD SPRING POND	STODDARD	B	11.78	4.8	112.3	499
COLE POND	ENFIELD	B	7	17.9	37.9	418
CONNER POND	OSSIPEE	B	35.01	19.2	242.8	274
CONSTANCE LAKE	PIERMONT	B	3.64	5.5	30.9	469
CORSER POND	ERROL	B	2.02	4.9	59.3	610
DARRAH POND	LITCHFIELD	B	7	8.4	35.9	54
DERBY POND	CANAAN	B	4.05	3.6	47.3	617
DUBLIN POND	DUBLIN	B	96.6	31.1	279.4	451
DUTCHMAN POND	SPRINGFIELD	B	11.29	3	47.6	470
EAST POND	LIVERMORE	B	2.7	7.9	113.7	774
ECHO LAKE	FRANCONIA	B	11.49	11.6	124.1	589
FLAT MOUNTAIN POND (1&2)	WATERVILLE	B	15.66	5.5	574.5	704
FROST POND	JAFFREY	B	41.8	3.7	116.2	334
GILMORE POND	JAFFREY	B	46.54	13.1	99.2	321
GRANITE LAKE	STODDARD	B	92.19	28.9	1084	390
GREELEY POND (UPPER)	LIVERMORE	B	0.81	7.9	63	684
GREGG LAKE	ANTRIM	B	78.95	11	1123.8	321
HALFMILE POND	ENFIELD	B	2.75	4.7	33.1	552
HALL POND, MIDDLE	SANDWICH	B	3.24	17	229.2	445
HARRISVILLE POND	HARRISVILLE	B	48.56	12.5	2710.6	402
ISLAND POND	WASHINGTON	B	81.83	16.8	647.5	429
IVANHOE, LAKE	WAKEFIELD	B	27.52	6.1	153.2	182
JENNESS POND	NORTHWOOD	B	94.09	8.5	640.1	200
KNOWLES POND	NORTHFIELD	A	24.28	17	84.8	227
LAUREL LAKE	FITZWILLIAM	B	62.73	13.4	269.1	335
LEDGE POND	SUNAPEE	A	44.56	5.2	256	399
LONESOME LAKE	LINCOLN	B	11.01	2.6	142.6	838
LONG POND	LEMPSTER	B	48.56	20.3	374.2	472
LONG POND	NORTHWOOD	B	40.55	14.7	386.3	176

Lake	Town	Class	Surface area (ha)	Maximum depth (m)	Drainage area (ha)	Elevation (m)
LOON LAKE	PLYMOUTH	B	45.28	8.8	973.7	149
MAY POND	WASHINGTON	B	60.3	7.6	1811.8	489
MILLEN POND	WASHINGTON	B	63.13	12.6	324.2	482
MONOMONAC, LAKE	RINDGE	B	287.78	7.8	4827.1	318
NORTHWOOD LAKE	NORTHWOOD	B	277.99	6.3	6064.7	157
NUBANUSIT LAKE	NELSON	B	289.35	30.2	1569	419
PEAKED HILL POND	THORNTON	B	4.45	4.8	108.2	352
PECKER POND	RINDGE	B	9.71	4.5	79.1	369
PLEASANT LAKE	DEERFIELD	B	199.71	19.8	925.1	176
PRATT POND	NEW IPSWICH	B	15.58	2.7	172.1	376
ROCKWOOD POND	FITZWILLIAM	B	30.76	6.7	367.1	339
RUSSELL POND	WOODSTOCK	B	15.78	22.5	149.6	502
SAND POND	MARLOW	B	64.38	18.3	315.9	470
SAWYER POND, LITTLE	LIVERMORE	B	4.45	8.8	24.6	631
SILVER LAKE	HARRISVILLE	B	134.64	26.2	607.4	402
SKATUTAKEE, LAKE	HARRISVILLE	B	105.58	6.2	3826.8	366
SOLITUDE, LAKE	NEWBURY	B	2.02	6.7	10.5	722
SPECTACLE POND	GROTON	B	18.53	11.8	84.5	250
STINSON LAKE	RUMNEY	B	141.64	23.5	2084.3	397
STONE POND	MARLBOROUGH	B	26.26	14.6	191	395
SUNCOOK POND, LOWER	BARNSTEAD	B	99.27	4.9	14152.4	168
SWEAT POND	ERROL	B	2.43	7	65.2	594
THORNDIKE POND	JAFFREY	B	107.24	7	1002	353
WACHIPAUKA POND	WARREN	B	9.02	9.1	79.8	455
WHITE LAKE	TAMWORTH	A	49.78	14.6	362	134

Methods

Calculating critical loads

The SSWC model is based on the principle that excess base cation production within a catchment area should be equal to or greater than the acid anion input, thereby maintaining the ANC above a pre-selected level (Reynolds and Norris, 2001). The model assumes steady state conditions, assumes that all sulfate in runoff originates from anthropogenic deposition and sea salt spray and is not adsorbed or retained in the watershed, and assumes that all chloride in the water comes from sea salt spray. Given a pre-selected critical ANC value, the critical load of acidity is simply the input flux of acid anions from atmospheric deposition, which gives the critical ANC when subtracted from the pre-industrial flux of base cations. Concentrations are multiplied by runoff Q to convert to fluxes. For a more detailed discussion of the SSWC model, see papers by Curtis, et al., 2001; Henriksen and Posch, 2001; and Henriksen, et al., 2002.

The critical load of acidity is expressed as:

$$CL_{ac} = ([BC^{*}]_{o} - [ANC]_{limit}) * Q$$

where:

CL_{ac} = critical load of acidity (S+N)
$[BC^{*}]_{o}$ = pre-industrial concentration of base cations (corrected for sea salt)
$[ANC]_{limit}$ = critical ANC concentration;

Q = annual runoff (m/yr)

The SSWC model uses in-lake water chemistry for the following inputs:

BC = sum of base cations (Ca, Mg, Na, K)
SO_4 = in-lake sulfate concentration
NO_3 = in-lake nitrate concentration

Appendix I of this appendix A provides the data used in the model for New Hampshire's acid ponds.

Sea salt corrections
The model applies a sea salt correction to the water chemistry concentrations. The equations below were applied to the Vermont lakes for their acid TMDL, and was applied to all the New England states and eastern Canadian provinces for the NEG/ECP assessment (Dupont et al, 2002). The equations correct for sea salt and convert concentrations from mg/L to ueq/L for use in the model. An asterisk (*) indicates the value has been corrected for sea salt (in the equations, * means multiplied by) and "U" before an ion indicates that it has been converted to ueq/L.

UCa^* = (Ca – (Cl * 0.0213)) * 49.9
UMg^* = (mg – (Cl * 0.0669)) * 82.26
UNa^* = (Na – (Cl * 0.557)) * 43.5
UK^* = (K – (Cl * 0.0206)) * 25.57
USO_4^* = (SO_4 – (Cl * 0.14) * 20.82
UNO_3^* = (NO_3-N) * 71.4
UCl = Cl * 28.21

*note: NO_3-N * 71.4 converts nitrate nitrogen in mg/L to the nitrate ion in ueq/L*

Pre-industrial base cation concentration and F factor
The pre-industrial (pre-acidification) non-marine flux of base cations from the watershed to a lake needs to be estimated. It cannot be estimated simply by measuring present day runoff concentrations because post-industrial acidic deposition has increased the leaching of base cations through ion exchange in the soils. Empirical relationships are invoked and an F factor is employed, which is defined as a ratio of the change in non-marine base cation concentrations due to changes in strong anion concentrations (Brackke, et al., 1990). The original F factor equation was recently modified to account for catchment areas with high and low runoff (Hindar and Henriksen, 1998). A more detailed discussion of the procedure can be found in Curtis et al., (2001) and Henricksen and Posch (2001). Suffice it to say here that New Hampshire used the same assumptions and equations as used by Vermont for their acid pond TMDL report (Pembrook, 2003).

The equation below presents the procedure for calculating the pre-industrial non-marine flux of base cations, where the subscripts $_o$ and $_t$ refer to original (pre-industrial) and current respectively, and the superscript * refers to corrected for sea-salt.

BC^*_o = BC^*_t – F factor ($USO4^*_t$ – $USO4^*_o$)

Where:
BC^*_t = sum of present day non-marine base cations (UCa^*+UMg^*+UNa^*+UK+)

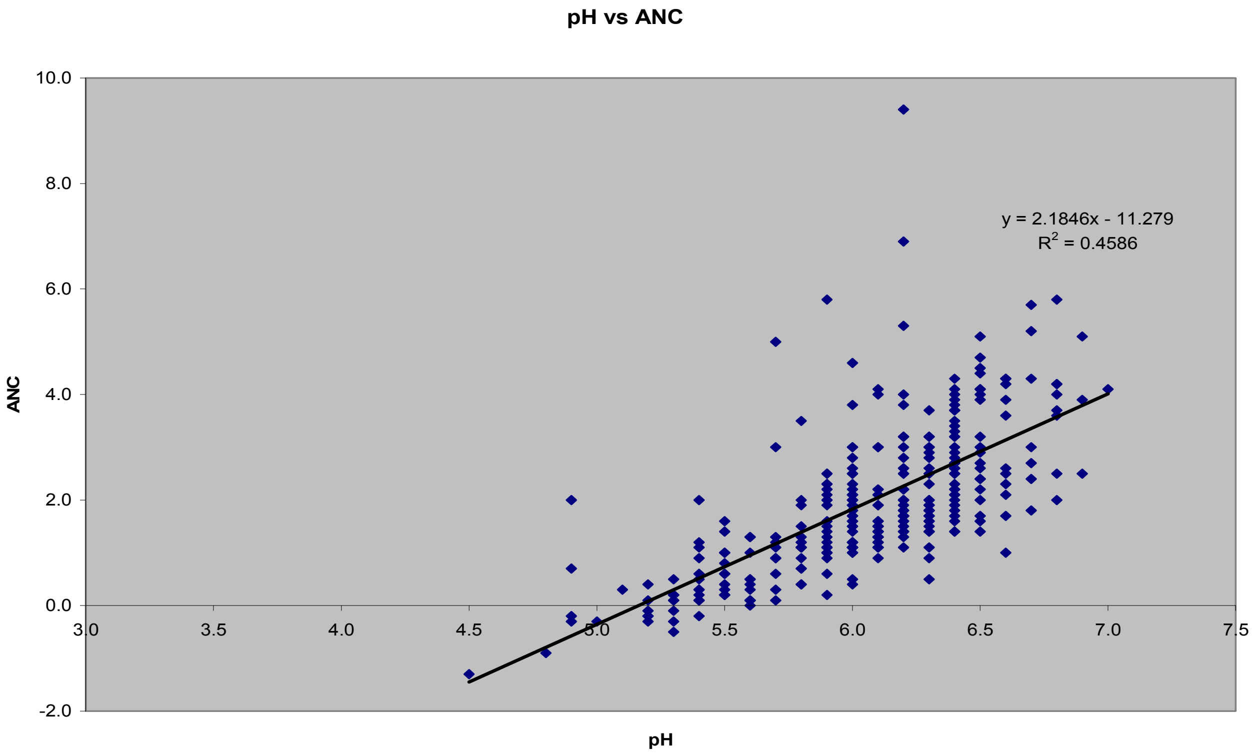
F-factor = annual base cation flux accounting for runoff in the catchment, which is = sin{ [(п/2)*Q*BC_t]/S}. S = base cation flux at which F = 1. S = 400 meq/m^2/yr was considered appropriate for Ontario lakes, was used by Vermont for their acid pond TMDL and is used here. Q = runoff.

$USO_{4\,t}^*$ = current non-marine, in-lake sulfate concentration

$USO_{4}{}^{*}{}_{o}$ = pre-acidification sulfate concentration. Vermont used estimates for Ontario (Henricksen, et al., 2002) that were also used for northeast North America (Jacques, et al., 2002) and are used here.

ANC Limit
The $[ANC]_{limit}$ is the lowest ANC concentration that does not damage selected biota (Henriksen and Posch, 2001). The model allows for an $[ANC]_{limit}$ to be pre-selected depending on the geographic area. Vermont chose an $[ANC]_{limit}$ of 2.5 mg/L (50 ueq/L). This is in line with limits of 40 to 50 ueq/L chosen in other North American studies (Hindar and Henricksen, 1998; Dupont, et al., 2002). For New Hampshire, the SWCC model is being used to estimate load reductions necessary to allow the ponds to meet the water quality criterion (pH = 6.5 or greater), which will require greater reductions than needed to protect biota. A pH of 6.0 is generally thought to be the criterion to protect most aquatic organisms (see, e.g., Schindler, 1988) and this is approximately equivalent to an ANC of 40 ueq/L for Quebec lake waters (Small and Sutton, 1986). Based on data from the ponds being evaluated, NHDES determined that an ANC of 3.0 mg/L (60 ueq/L) approximates a pH of 6.5 (see Figure 1 below) and have therefore selected 3.0 mg/L as the $[ANC]_{limit}$.

Figure 1. pH vs ANC for acid impaired ponds



Annual surface runoff estimates: Q
Annual estimates of surface runoff (Q) were obtained from Knox and Nordenson (1955) or Randall (1996). Runoff estimates are provided in Table 2 of Appendix I.

Interpreting critical load values

The calculated critical load for a lake is considered to be an inherent property of the lake and its catchment area. A positive value indicates that the waterbody has some tolerance for acid inputs. The greater the value, the greater the tolerance for acidification. Very high values suggest conditions may be acceptable for sensitive organisms regardless of deposition scenarios whereas low values suggest sensitivity to acidification (Hindar and Henriksen, 1998).

Negative critical load values occur when the selected ANC_{limit} is higher than the calculated original base cation concentration (BC^*_o). Such results imply that the water quality criterion (pH 6.5 as represented by ANC 3.0) is greater than what nature provides. In other words, the natural conditions were such that the original (pre-industrialization) ANC was lower than the selected ANC for protection of biota (Henriksen, et al., 1992). The critical load for such lakes is converted to zero in order to calculate exceedances. For these lakes with a critical load of zero, the critical load will always be exceeded even assuming the strongest emission reduction scenarios, and the lakes will never attain a pH of 6.5.

The critical loads for New Hampshire's acid impaired ponds ranged from -147 (Island Pond in Washington) to 149 (Upper Greeley Pond) with a mean value of 44 (the negative values were averaged as negative values). Despite the wide range in values, caused primarily by just two or three ponds, the mean value of all lakes was of the same order of magnitude as the mean value that Vermont determined for their acid impaired ponds (29).

Sensitivity of the model

The SSWC model is highly sensitive to two parameters: the ANC_{limit} and the F-factor. The ANC_{limit} selected was based on the pH water quality criterion of 6.5 and the relationship between pH and ANC. DES chose a limit of 60 ueq/L (3.0 mg/L), which is more protective than the 50 ueq/L limit used by Vermont (VTDEC, 2003) and the 40 ueq/L limit used by for the NEG/ECP analysis (Dupont, et al., 2002). Lowering the AND_{limit} would increase the critical load values and decrease the excess load values.

The F-factor accounts for the rate of base cation leaching from the watershed. Vermont, the NEG/ECP analysis for northeast North America and studies of lakes in Ontartio, Canada (Henriksen et al., 2002; Hindar and Henriksen, 1998) all used an F-factor based on a Norwegian estimate that takes into account high and low runoff from a catchment area. The same F-factor was assumed appropriate for New Hampshire lakes.

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